# Technological Innovation, Financialization and Ecological Footprint: Evidence from BEM Economies

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# Technological Innovation, Financialization and Ecological Footprint: Evidence from BEM Economies

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**Abstract**

Despite the growing interest in researches on the impact of technological development on the carbon emissions, the effect of technological innovation on the other indicators of environmental degradation is of little interest. In order to close this gap, the aim of this study is to determine the effects of technological innovation on both carbon emission and ecological footprint for big emerging markets (BEM) countries. In doing so, the environmental impacts of the financialization process are also explored, in line with the fact that these countries face constraints in financing technological developments. In this context, the effects of technological development, financialization, renewable energy and non-renewable energy consumption on environmental degradation are examined through the second-generation panel data methods for the period 1995-2016. The findings indicate that technological innovation is effective in reducing carbon emissions, but does not have a significant impact on the ecological footprint. Namely 1% increase in technological innovations reduces carbon emission by 0.082% - 0.088%. Moreover, it is found that financialization harms environmental quality for both indicators of environment because 1% increase in financialization increases carbon emissions by 0.203% - 0.222% and increases ecological footprint by 0.069% - 0.071%.

**Keywords:** Technological Innovation, Financialization, Environmental Degradation, Carbon Emission, Ecological Footprint, Panel Data

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## 1. Introduction

In recent years, due to the serious effects of the economic policies on the environment, there are intensive discussions on the concepts pointing to environmental destruction such as global warming and climate change. Accordingly, the Environmental Kuznets Curve (hereafter, EKC) hypothesis that deals with the effects of economic growth on environmental destruction has become a popular research subject. The hypothesis is basically derived from the inverted U-shaped relationship between economic growth and income inequality expressed in the study of Simon Kuznets (1955), but Grossman and Krueger (1991) and Shafik and Bandyopadhyay (1992) pioneered the adaptation of this hypothesis to environmental destruction. EKC hypothesis briefly states that in the first phase of economic growth, environmental degradation increases due to the increase in income level, and environmental destruction decreases after exceeding a certain threshold in income level (Dinda, 2004). According to Grossman and Krueger (1991), it is possible to divide the impact of the economic activities on environmental destruction into three groups as scale effect, composition effect and technology effect. The scale effect is an effect explaining the increase in the environmental degradation caused by the economic activities carried out by using fossil fuels depending on the increase in commercial activities in the period when the national economies started to grow. However, in the later stages, environmental destruction decreases due to the changes in the commercial policies of the countries in which the economic growth process continues, especially due to the specialization in certain areas where the level of pollution is less (composition effect) and due to the improvement in technology and increasing competitive advantage (technological effect).

Despite the only cause of environmental destruction or environmental quality has been hypothesized as economic growth, it has been determined by country experiences that just economic enrichment is not enough to reach the final stage of the hypothesis. Therefore, the researchers strived to explain the difference in the effects of enrichment on the environment by focusing on the indicators triggered by economic growth and the indicators triggering economic growth. In this context, some recent studies explained mentioned differences by financialization (Shahbaz et al. 2018a; Ahmad et al. 2018; Khan et al. 2019; Destek and Sarkodie, 2019; Nasir et al. 2019; Zafar et al., 2019; Destek, 2019a; Liu and Song, 2020; Shahbaz et al. 2020); globalization (Rafindadi and Usman, 2019; Ahmed et al., 2019; Destek, 2019b; Balsalobre-Lorente et al., 2020; Bilgili et al., 2020; Destek and Sinha, 2020); urbanization (Salahuddin et al., 2019; Wang and Su, 2019; Ulucak et al., 2020); industrialization (Asumadu-Sarkodie and Owusu, 2017; Liu and Bae, 2018; Dong et al., 2019; Wang et al., 2020); energy portfolio (Destek et al. 2018; Bekun et al., 2019; Alola et al., 2019; Sharif et al., 2020; Destek and Aslan, 2020; Erdogan et al., 2020); human capital (Ahmed and Wang, 2019; Chen et al., 2019; Sarkodie et al., 2020; Zafar et al., 2020); technological innovation (Yu and Du, 2019; Hashmi and Alam, 2019; Sinha et al. 2020; Khan and Ulucak, 2020) levels of the countries.

In spite of the fact that all the mentioned factors have direct or indirect effects on the environment, environmental regulations and technological progress are accepted as the most important prerequisite for reaching the final stage of the EKC hypothesis (Yin et al. 2015). In addition to its direct effects, it is stated that technological innovation manages the relations among the determinants of environmental quality and also that innovation supported commercial activities also serve environmental quality (Torras and Boyce, 1998). In particular, the effective support of innovative activities specific to the energy sector decreases environmental damage by increasing renewable energy use and energy efficiency (Vukina et al., 1999). However, access to high-cost environmental technologies is not possible especially in developing countries due to the fund constraint. In this context, low-income developing countries are still obliged to have a production structure based on fossil energy sources, while high-income developing countries (emerging economies) can obtain the necessary funds for environmental technologies through the financial system. Therefore, although the financialization process appears to indirectly contribute to environmental quality, there are also debates that it increases environmental degradation.

Many scenarios with opposite views regarding the environmental effects of the financialization process come to the fore. In the optimistic scenario, it is stated that the technologies that provide savings in energy use and help reduce environmental pollution will be easier and lower cost. In addition, according to this view, the environmental dominance of firms, which are managed with a more effective financial system, leads to a reduction in the environmental destruction of these firms. (Claessens and Feijen, 2007; Tamazian et al. 2009). According to the opposite view, the impact of financial development on environmental destruction arises for various reasons. The first of these is to attract foreign direct investments to the country at the expense of environmental destruction to support financial development and economic growth. Secondly, the widespread use of financial instruments increases the power of consumers to purchase products such as automobiles, refrigerators and air conditioners. It causes more environmental degradation by purchasing such products. Finally, it is an increase in energy consumption and therefore environmental damage due to frequent use of new projects and new investment channels in order to reduce financing costs, diversify financing channels and distribute business risk (Zhang, 2011). Apart from all these arguments, some empirical studies suggest that there is no relationship between financial development and carbon emissions (Shahbaz, et al. 2018b). Therefore, the following research questions need to be answered: i) is technological progress an environmentally blessing or a curse? ii) does the expansion and deepening of the financial system fund long-term profitable environmental projects or pursue short-term profit?

Based on above debates, this study aims to examine the impact of technological innovation and financialization on environmental degradation in Big Emerging Markets (BEM) countries: Argentina, Brazil, China, India, Indonesia, Mexico, Poland, S. Africa, S. Korea and Turkey. For this purpose, the impact of technological development, financial development, renewable energy consumption and non-renewable energy consumption on environmental degradation is analyzed with second generation panel data methodologies for the period from 1995 to 2016. In doing so, to compare the atmospheric and total environmental effect of explanatory variables, both carbon emissions and ecological footprint are used as environmental degradation indicators. The reason for using ecological footprint of Wachernagel and Rees (1996) is that the ecological footprint is seen as a more appropriate measure representing environmental degradation than other environmental indicators (Wachernagel and Rees, 1996) because it simultaneously measures, grazing land, fishing grounds, forest land, settled land and carbon footprint (Lin et al 2016). Moreover, the reason why this country group is preferred in the study is that BEM countries have a more developed financial system and higher technology investments than other developing countries. In addition, according to the recent report of Muntean et al. (2008), BEM 10 countries are responsible for 45.71% of global carbon emissions in 2017. Therefore, identifying the triggers of the carbon emissions of these countries and finding solutions to this will also play an important role in reducing global carbon emissions.

The contributions of the study to existing literature are fourfold: i) this is the first study to examine the determinants of environmental degradation in BEM countries. ii) the study uses environmental-related technologies as an indicator of technological innovation to clearly observe the environmental-efficiency of technological development. iii) the study also uses financial development index as an indicator of financial development instead of private credits that widely used in the literature because the financial development index includes many sub-indices about financial system. iv) the study compares the effects of explanatory variables on carbon emissions and ecological footprint instead of focusing only atmospheric pollution. v) unlike previous studies, the study uses second-generation panel data methodologies to take into account the possible cross-sectional dependence among observed countries.

The paper is organized as follows: Section 2 reviews and summarizes the previous studies. Section 3 describes the empirical models, data and methodology. Section 4 presents and discusses the empirical results. Finally, Section 5 concludes the study with policy implications.

## 2. Literature Review

Since the main purpose of this study is to observe the impact of technological innovation and financialization on environmental degradation, we categorize the section with two parts as financialization and environment nexus and technological innovation and environment nexus. In first part, we focus on environmental impact of financialization and the second part includes the previous studies on environmental impact of technological innovation.

### 2.1. Financialization and Environment

It is seen that studies investigating the effect of financialization on environmental quality have obtained different findings. In general, the main view that financialization increases environmental quality is stated that in parallel with the improvement in economic growth with financialization, energy will be used efficiently and the possibility of accessing new technologies that increase environmental quality will increase, thus environmental pollution will decrease (Islam et el. 2013). On the other hand, the opposite view argues that the economic growth provided by the increase in financialization may cause more industrial pollution and environmental degradation (Jensen, 1996). As one of the pioneering studies on financialization and environmental degradation nexus, Tamazian et al. (2009) analyzed the relationship between financial development, economic growth and carbon emissions in BRIC countries between 1992-2004 with the standard reduced-form modeling approach. In the study, the ratio of deposit money bank assets to GDP, the capital account convertibility and financial liberalization are used as indicators of financial development. In conclusion, it is stated that especially the developments in the capital market and the banking sector and the FDI inflows in these sectors are effective in reducing environmental degradation.

Similar to the findings of this study, Jalil and Feridun (2011) also found that financial development reduces carbon emissions and stated that the reduction of carbon emissions in China is the possible result of the establishment of new environmental facilities that are realized with the capital accumulation provided by financial development and provide waste disposal. In addition, the study also argued that the financialization process required for reducing environmental pollution should be continued by supporting the problematic loans with various privatization reforms. Shahbaz et al. (2013a) reach a similar result for Malaysia and attributed this finding to that financial development in Malaysia providing the financing required for environmental development projects at a lower cost and the environmental projects carried out with financial development to achieve significant efficiency in fossil fuel consumption throughout the country. Shahbaz et al. (2013b) also validated the environmental pollution reducing effect of financial development in South Africa.

Opposite to the above studies, some studies found the environmental degradation increasing effect of financial development. For instance, Zhang (2011) analyzed the impact of financial development on carbon emission for China between 1980 and 2009 by using variance decomposition method and reached the finding that financial development, especially the effect of financial intermediation transactions, increases carbon emissions. This is mainly attributed to the deficiencies in adapting the direction of use of FDI movements entering China to encourage low-carbon development and the development of financial intermediation activities in China, which lead to a significant increase in carbon emissions. Shahbaz et al. (2015) also concluded that financial development increases environmental destruction and explained the reason of this finding that the lack of obstacles and sanctions in promoting and increasing energy use to ensure unsustainable high economic growth, as in many developing countries such as India. Similarly, Shahbaz et al. (2016) for Pakistan and Baloch et al. (2019) obtained for 59 Belt and Road countries. The findings obtained in these studies are attributed to the financial developments in the banking sector, the fact that the financial resource distribution mechanism of the banking sector in selected countries is not monitored after the resource allocation, the companies that use their funds in practices lacking environmental control are punished by various methods such as interest rate increases or tax increases.

There are also some studies found an indirect effect of financialization instead of the direct effect such as Al Mulali and Sab (2012) observed the relationship between financial development, energy consumption, carbon emission and economic growth in Sub-Saharan African countries for the period of 1980-2008, and concluded that increased energy use due to economic growth and financial development significantly increases carbon emissions. Boutabba (2014) discussed the relationship between carbon emissions, financial development, economic growth, energy consumption and openness in India between 1971-2008 using with ARDL bound test. According to the findings, the increase in financial development increases the environmental degradation by increasing the energy use.

Based on the parabolic function of EKC hypothesis, Moghadam and Lotfalipour (2014) examined the possible parabolic impact of financial development on environmental pollution between 1970-2011 using the ARDL method and found that there is a positive relationship between financial development and carbon emissions, but this relationship evolved negatively after achieving a certain level of financial development, therefore, the study argued that there is an inverted U-shaped relationship between these twin variables. According to the study, this situation is a result of the investments supported by financial development that only focus on the size of industrial activities in Iran and the developments that will increase environmental protection in the sector are ignored. Furthermore, some studies argue that there is no any statistical relationship between financialization and environmental degradation. Ozturk and Acaravcı (2013) examined the nexus between financial development, trade openness, energy consumption and carbon emissions in Turkey for the years of 1960-2007 and the findings show that financial development has no effect on carbon emissions.

Similar to our study, there are also some studies employ the second-generation panel data methodologies to check the financialization-environment nexus. For instance, Wang et al. (2019) utilized methods that allow cross-section dependency while examining the relationship between financialization and environment for OECD countries. According to this study, financial development plays an important role in reducing CO2 emissions by funding companies to acquire environmentally friendly technologies in the production process. Similar findings were obtained from the studies of Dogan and Seker (2016) for the top renewable energy generator countries and Awan et al. (2020) for the Middle East and North African countries. On the contrary, Bayar et al (2020) predicted that for post-transition European economies, funds other than energy-saving technological developments or financial developments that are directed towards production channels only increase environmental degradation.

**2.2. Technological Innovation and Environment**

Similar to the studies on the relationship between financialization and environment, it is seen that mixed results are obtained from the studies examining the effects of technological innovation on the environment, depending on the used methodology, observed country/country group or considered period. But still, as hypothesized, empirical findings often appear to be that technological innovation contributes to environmental quality. For instance, Ali et al. (2016) examined the relationship between technological innovation and carbon emission in Malaysia and the finding about pollution reducing effect of technology was attributed to the fact that technological developments in Malaysia were based on green and environmentally friendly technology. Ibrahiem (2020) investigated the nexus for Egyptian economy emphasized that low and zero carbon energy supply is important in the application of technologies, especially in energy-intensive sectors such as the cement sector. Ahmed et al. (2016) also found the evidence that technological progress reduces carbon emission. Moreover, Hang and Yuan-Sheng (2011) considered the possible parabolic relationship between mentioned variables and found that the effect of technological development on carbon emission is positive in the first stage and negative in the later stages in China. In other words, it is found that there is an inverted U-shaped relationship between both variables. This situation is attributed to the increase in investment and higher emissions due to the emergence of more technological innovations in the first phase of industrialization in the country's economy. In the later stages of industrialization, the positive impact of technology has been explained by the change in consumption patterns from the energy-intensive manufacturing sector to the more environmentally friendly service sector and the emergence of alternative energy sources.

It is surprisingly seen that most of the studies focusing on only the causal nexus between technological innovation and environment found that there is no significant relationship between the variables. For instance, Fei et al. (2014) examined the relationship between renewable energy, economic growth, carbon emissions and technological innovation in Norway and New Zealand for the period 1971-2010 with the Granger causality test. According to the results, while it is concluded that there is a bidirectional causality between carbon emission and technological innovation for Norway, it is estimated that there is no causal relationship between these variables in New Zealand. Irandoust (2016) searched the relationship between technological innovation, renewable energy and carbon emissions in Denmark, Finland, Norway, and Sweden for the period from 1975 to 2012. The study used the R&D expenditures in the energy sector as an indicator of technological innovation with employing the causality test of Toda and Yamamoto (1995) and concluded that there is a unidirectional causality from technological innovation to renewable energy, but there is no significant causal relationship between carbon emission and technological innovation. Fan and Hossain (2018) analyzed the relationship between trade openness, technological innovation and carbon emissions for the period of 1974-2016 in China and India with the Toda-Yamamoto causality test. According to the findings, while there is a bidirectional causal relationship between twin variables in China, there is a unidirectional causality from technological development to carbon emission in India. The difference of the findings between China and India is attributed to India's being far behind the world standards in terms of preparation for technological development. Yii and Geetha (2017) investigated the relationship between technological innovation and carbon emissions in Malaysia for the period of 1971-2013 with the VECM Granger causality test. The findings have revealed that there is no relationship between technological innovation and carbon emissions. Samargandi (2017) tested the relationship between sectoral value added, technological development and carbon emissions between 1970 and 2014 in Saudi Arabia with the ARDL bound test and concluded that technological development does not have a significant effect on carbon emissions. This situation is attributed to the fact that 100% fossil fuel is still used as the primary energy source in the country, the petroleum supply with low prices is abundant and therefore innovative activities that enable the use of clean energy resources are ignored.

Moreover, there are also studies analyzing the relationship between technological development and the environment by considering cross-sectional dependency. For some recent studies, Khattak et al (2020) analyzed the impact of technological innovation, economic growth and renewable energy use on carbon emissions in the BRICS countries for the period of 1980-2016. Findings have shown that innovation activities have failed to reduce carbon emission for BRICS countries except Brazil. Similarly, Ali et al (2020) concluded that innovation activities in 33 selected European Union countries reduced carbon emissions. This finding attributed to the diffusion of technological developments that provide energy efficiency.

## 3. Data and Methodology

### 3.1. Data

Following above debate, the annual data from 1995 to 2016 is observed to examine the impact of technological innovation and financialization on environmental degradation based on the IPAT environmental model of Ehrlich and Holdren (1971) which is widely used theoretical model by environmental economists. The IPAT environmental model can be summarized as follows:

$$I = P \times A \times T \quad (1)$$

where I shows the environmental impact, P means population, A indicates economic activities and T implies technological level. In the following years, Dietz and Rosa (1994; 1997) transformed this basic model into a stochastic model and obtained the STIRPAT (Stochastic Impacts by Regression on Population, Affluence and Technology) model. While creating the empirical model, we follow the STIRPAT model, but we excluded the population variable from the model by using countable variables in the per capita form. In this direction, our empirical model is as follows;

$$lnED_{it} = a_0 + a_1 lnR_{it} + a_2 lnNR_{it} + a_3 lnTEC_{it} + a_4 lnFIN_{it} + \varepsilon_{it} \quad (2)$$

where ED is environmental degradation and proxied by two different indicators such as carbon dioxide emission (CO) and ecological footprint (EF), R is renewable energy consumption, NR is non-renewable energy consumption, TEC is technological innovation and FIN indicates financialization. In empirical procedure, CO is measured in per capita carbon emissions in metric tons, EF is used as per capita ecological footprint in gha, R (NR) is used as per capita renewable (non-renewable) energy consumption in kwh, TEC is measured as patent number in environmental-related technologies and FIN is used as financial development index.

In regard to the source of dataset, CO data is obtained from Gilfillan et al. (2019), UNFCCC (2019), BP (2019) and EF data is obtained from Global Footprint Network. R and NR data are obtained from Energy Information Administration, TEC data is retrieved from OECD statistics and FIN data is obtained from Financial Development Index of International Monetary Fund. In empirical analysis, to avoid scaling differences and to normalize the series, all variables are used in natural logarithmic form.

## 3.2. Methodology

### 3.2.1. Preliminary Tests

In panel data procedure, it is necessary to choose the right estimator to obtain consistent and reliable results for policy recommendations. Based on the fact that the effects of the 2008 global financial crisis spread across almost all countries, it is anticipated that estimators (called as first-generation estimators), which do not take into account inter-country dependency, are not expected to yield reliable results. Accordingly, when using panel data techniques, it is most likely necessary to test the interdependence between countries, in other words, the cross-sectional dependence (hereafter, CSD). In this study, CSD issue is investigated by CD test developed by Pesaran (2004). Then, it is also necessary to observe the stationarity process, which is important in all econometric predictions. Therefore, the CIPS unit root test developed by Pesaran (2007) is used in the study since the unit root test to be used should be a test that also allows CSD. At the end of the preliminary tests, the test of whether the long-term relationship between the variables is valid affects the choice of the estimator to be used. Accordingly, the validity of the mentioned relationship is investigated through the ECM-Based cointegration test developed by Westerlund (2007).

### 3.2.2. Panel Long-Run Estimators

After validating the cross-sectional dependent cointegration among variables, the coefficient of cointegrated regressor should be searched with an estimation technique that allows cross-sectional dependence. Thus, we conduct CUP-FM (continuously-updated and fully-modified) and CUP-BC (continuously-updated and bias-corrected) estimators developed by Bai et al. (2009). These estimators augment the basic panel regression model and assume cross-sectional dependence and error term ($\varepsilon_{it}$) [e.g. Bai and Kao, 2006] as follows:

$$y_{it} = a_i + \beta x_{it} + \varepsilon_{it} \quad (3)$$

$$\varepsilon_{it} = \lambda_i' F_t + \mu_{it} \tag{4}$$

where $F_t$, $\lambda_i'$ and $\mu_{it}$ indicate the vector of common factors, corresponding factor loadings and the idiosyncratic component of the error term, respectively. The computation process of CUP-FM is based on repeatedly estimating coefficients and long-run co-variance matrix until reaching the convergence as follows:

$$\hat{\beta}_{Cup} = \left[\sum_{i=1}^{n}\left(\sum_{t=1}^{T}\hat{y}_{it}^{+}(\hat{\beta}_{Cup})(x_{it}-\bar{x}_i)' - T\left((\lambda_i'(\hat{\beta}_{Cup})\hat{\Delta}_{F\varepsilon i}^{+}(\hat{\beta}_{Cup}) + \hat{\Delta}_{\mu\varepsilon i}^{+}(\hat{\beta}_{Cup})\right)\right)\right] \times$$

$$\left[\sum_{i=1}^{n}\sum_{t=1}^{T}(x_{i,t}-\bar{x}_i)(x_{i,t}-\bar{x}_i)'\right]^{-1} \tag{5}$$

where $\hat{y}_{it}^{+} = y_{it} - (\hat{\lambda}_i'\widehat{\Omega}_{F\varepsilon i} + \widehat{\Omega}_{\mu\varepsilon i})\widehat{\Omega}_{\varepsilon i}^{-1}\Delta x_{it}$, $\widehat{\Omega}_{F\varepsilon i}$ and $\widehat{\Omega}_{\mu\varepsilon i}$ are estimated long-run co-variance matrices and $\hat{\Delta}_{F\varepsilon i}^{+}$ and $\widehat{\Omega}_{\mu\varepsilon i}$ are estimated one-sided long-run co-variance.

There are also some reasons for using the CUP-FM and CUP-BC estimators in this study. First, similar to our preferred cointegration test, these estimators are also consistent tests in the case of exogenous explanatory variables. In addition, these estimators can be used for the variables that integrated from different orders. Moreover, since the CUP-FM estimator is a test developed based on the fully modified OLS estimator which uses the Bartlett-Kernel procedure, especially it can also be used in possible autocorrelation and heteroskedasticity situations (Kiefer and Vogelsang, 2002). Finally, both estimators are robust in case of endogeneity (Bai et al., 2009).

## 4. Empirical Results

### 4.1. The Results of Preliminary Tests

In the first step of empirical analysis, we employ some preliminary tests (i.e. CSD, Unit Root and Cointegration) to prefer the most suitable estimator for our empirical models. In doing so, first, the possible CSD among BEM countries are examined with CD test and the findings are presented in Table 1. Based on the results, the null hypothesis of there is no CSD is clearly rejected therefore the importance of considering the impact of globalization on our indicators is validated.

**[INSERT TABLE 1 HERE]**

Based on the confirmation of CSD, since the stationarity process of variables should be searched with a unit root test that allows CSD, we employ the CIPS unit root test of Pesaran (2007). The results from Table 1 show that the unit root process can not be rejected in the level form of variables. However, all variables have become stationary in first differenced form thence the evidence that all variables are integrated of order one is confirmed.

In final step of preliminary analysis, the existence of long-run relationship between variables for both models are investigated with the ECM-Based panel cointegration test of Westerlund (2007) and the findings are shown in Table 2. In first model, the null of no cointegration is rejected by $G\tau$, $P\tau$ and $P\alpha$ statistics. In case of the second model, the null is also rejected by $G\tau$ and $P\tau$ statistics. Therefore, we confirm the validity of cointegration relationship between variables for both models and this result allows us to search the cointegrating coefficients of explanatory variables on environmental degradation.

**[INSERT TABLE 2 HERE]**

### 4.2. Determinants of Environmental Degradation

As financialization, technological innovation, renewable and non-renewable energy consumption are cointegrated with the environmental degradation indicators, the long-run impact of these variables on different degradation proxies is observed with CUP-FM and CUP-BC estimation techniques that allows CSD. First, we examine the determinants of carbon emissions (CO) and present the findings in Table 3. At a first glance, both estimation results show that increasing renewable energy consumption reduces carbon emissions while non-renewable increases it. In addition, the hypothesis that technological development is efficient on carbon mitigation is confirmed. However, it is surprisingly found that financialization harms the atmospheric quality in BEM countries.

**[INSERT TABLE 3 HERE]**

In case of ecological footprint, the findings from Table 4 reveal that renewable energy consumption also reduces the ecological footprint as it reduces the carbon emissions. However, unlike carbon emission function, the ecological footprint increasing role of non-renewable energy use is not observed. Similarly, it is also found that technological innovation does not significantly affects ecological footprint. However, the hypothesis that financialization harms environmental quality is also supported because financial development increases ecological footprint.

**[INSERT TABLE 4 HERE]**

Overall, our findings reveal that renewable energy consumption reduces environmental degradation for both environment indicators and the finding is consistent with the findings of Alola et al., (2019) and Sharif et al., (2020). The environmental degradation reducing effect of renewable energy consumption means that the renewable energy consumption level of selected countries has reached to adequate level to combat with environmental destruction. In addition, we found that non-renewable energy consumption increases carbon emissions but does not affect ecological footprint. The degradation increasing effect of non-renewable energy use is also validated by the studies of Bekun et al., (2019); Destek and Aslan, (2020) and Erdogan et al., (2020). This finding is an expected situation because fossil energy sources are accepted as the most pollutant energy sources. When the environmental effects of technological innovation are evaluated in line with the main purpose of the study, it is seen that technological progress reduces carbon emission in line with the studies of Ahmed et al. (2016) and Ibrahiem (2020). However, it has been observed that technological progress does not have a significant impact on the ecological footprint. This indicates that technological research focuses only on targets that increase atmospheric quality in selected countries. Finally, it is found that financialization accelerates deterioration in all environmental indicators. The environmental degradation increasing effect of financial development is also confirmed by Ali et al. (2019). This finding emphasizes that the countries observed have failed in terms of regulation policies that will encourage the financial system to provide funding for environmentally friendly technologies.

**[INSERT TABLE 5 HERE]**

We also use the two-way fixed effect model for robustness check and present the findings in Table 5. As a seen, the findings from two-way fixed effect model is consistent with the continuously updated estimators. Namely, the results validated the evidence that increasing renewable energy consumption and technological innovation reduces the carbon emissions while non-renewable energy consumption and financialization increases it. In addition, for ecological footprint model, increasing renewable energy reduces ecological footprint while financialization increases the degradation level of countries. Similar to the findings from CUP estimators, these findings also confirmed that non-renewable energy use and technological innovation do not have any significant impact on ecological footprint.

## 5. Conclusions and Policy Implications

This study explores the impact of technological innovation on environmental degradation by controlling the financialization, renewable energy consumption and non-renewable energy consumption in Big Emerging Markets (BEM) countries. In addition, to compare how the atmospheric pollution and total environmental degradation affected by technological innovation, both carbon emissions and ecological footprint are used as an indicator of environment. In doing so, the period from 1995 to 2016 is analyzed with second-generation panel data methodologies. In detail, the stationary properties of variables are examined with CIPS unit root test, existence of long-run relationship between variables are searched with ECM-based panel cointegration test and the long-run impacts of the regressors are probed with Cup-FM and Cup-BC estimation techniques.

The results of empirical analysis can be summarized as follows: i) increasing renewable energy consumption reduces both carbon emissions and ecological footprint. ii) increasing non-renewable energy consumption increases carbon emissions while it does not significantly affect the ecological footprint. iii) technological innovation reduces carbon emissions while it does not significantly affect ecological footprint. iv) financialization increases both carbon emissions and ecological footprint. Based on these findings, the first one indicates that renewable energy share in total energy portfolio of these countries has reached to level that reduce environmental degradation. Therefore, it can be said that continuing green energy policies to increase mentioned rate plays a key role in success for combating environmental destruction. In addition, the second finding implies that non-renewable energy consumption is a factor that mainly increases atmospheric pollution but has an almost insignificant effect on total environmental degradation. In this context, the conversion to renewable energy should be accelerated in order to reduce atmospheric pollution. Thirdly, it is surprisingly seen that technological innovations act mainly with the focus of reducing atmospheric pollution. On the other hand, it seems there is no technological progress to reduce damage on cropland, grazing land, fishing grounds, build-up lands and forest land. Therefore, the innovative researches should also be directed to create improvements in ecological footprint indicators. The fourth and most negative picture clearly reveals the fact that the financial system accelerates environmental degradation. This is largely due to the fact that emerging economies are in need of funds provided from the financial system in their development strategies and that they are limited in terms of environmentally friendly regulation policies. However, it is observed that the development policy, which is pursued solely based on economic enrichment, is an important obstacle to reaching other sustainable development targets. Moreover, the problems that will arise as a result of environmental degradation eliminate the economic gains in the long term. Accordingly, it will be a more rational policy to regulate the financialization process to provide funding projects especially for environmentally friendly technological progress. When the findings are evaluated on financialization, technological innovation and environmental transfer mechanism, it is concluded that technological innovation activities that reduce environmental pollution do not benefit the financial sector, contrary to expectations. That is to say, technological development in these countries reduces environmental degradation, but the financing opportunities provided by the financialization process to environmental technologies are insufficient. In fact, the financial sector provides more funds for areas that increase environmental pollution in big emerging economies.

Considering the rapidly increasing production levels and emissions of BEM countries, it is of great importance that developed countries with higher technology levels compared to BEM countries share environmental-friendly technologies with BEM countries in terms of global emission reduction. In addition, considering the rapid industrialization and innovation processes, other countries should take measures to restrict the import of high-emission industrial products rather than low-cost goods imports in their trade with BEM countries.

Finally, we should note about the limitations of this study to create a roadmap for future studies. Although this study provides information about the effects of technological development and financialization on overall environmental degradation, identifying the impact on disaggregated environmental indicators will allow more detailed policy recommendations. Namely, determining the effects of technological innovation and financialization on cropland, grazing land, fishing grounds, forest land, built-up land along with carbon footprint can be compared by using subcomponents of the ecological footprint as dependent variables instead of total ecological footprint.

**Declarations**

**Ethical approval and consent to participate**

Not applicable

**Consent to publish**

Not applicable

**Author contributions**

MAD initiated and designed the study. MM reviewed the literature and collected the dataset. MAD carried out empirical analysis. MAD and MM have jointly interpreted the empirical findings, revised and completed the manuscript. All authors read and approved the final manuscript.

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**Availability of data and materials**

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## References

Ahmad, M., Khan, Z., Ur Rahman, Z., & Khan, S. (2018). Does financial development asymmetrically affect CO2 emissions in China? An application of the nonlinear autoregressive distributed lag (NARDL) model. *Carbon Management*, *9*(6), 631-644.

Ahmed, A., Uddin, G. S., & Sohag, K. (2016). Biomass energy, technological progress and the environmental Kuznets curve: Evidence from selected European countries. *Biomass and Bioenergy*, *90*, 202-208.

Ahmed, Z., & Wang, Z. (2019). Investigating the impact of human capital on the ecological footprint in India: An empirical analysis. *Environmental Science and Pollution Research*, *26*(26), 26782-26796.

Ahmed, Z., Wang, Z., Mahmood, F., Hafeez, M., & Ali, N. (2019). Does globalization increase the ecological footprint? Empirical evidence from Malaysia. *Environmental Science and Pollution Research*, *26*(18), 18565-18582.

Ali, H. S., Law, S. H., Lin, W. L., Yusop, Z., Chin, L., & Bare, U. A. A. (2019). Financial development and carbon dioxide emissions in Nigeria: evidence from the ARDL bounds approach. *GeoJournal*, *84*(3), 641-655.

Ali, M., Raza, S. A., & Khamis, B. (2020). Environmental degradation, economic growth, and energy innovation: evidence from European countries. *Environmental Science and Pollution Research International.*

Ali, W., Abdullah, A., & Azam, M. (2016). The dynamic linkage between technological innovation and carbon dioxide emissions in Malaysia: an autoregressive distributed lagged bound approach. *International Journal of Energy Economics and Policy*, *6*(3), 389-400.

Al-Mulali U, Tang CF, Ozturk I (2015) Estimating the environment Kuznets curve hypothesis: evidence from Latin America and the Caribbean countries. Renewable and Sustainable Energy Reviews 50:918-924.

Al-Mulali, U., & Sab, C. N. B. C. (2012). The impact of energy consumption and CO2 emission on the economic growth and financial development in the Sub Saharan African countries. *Energy*, *39*(1), 180-186.

Alola, A. A., Bekun, F. V., & Sarkodie, S. A. (2019). Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. *Science of the Total Environment*, *685*, 702-709.

Asumadu-Sarkodie, S., & Owusu, P. A. (2017). The causal effect of carbon dioxide emissions, electricity consumption, economic growth, and industrialization in Sierra Leone. *Energy Sources, Part B: Economics, Planning, and Policy*, *12*(1), 32-39.

Awan, A. M., Azam, M., Saeed, I. U., & Bakhtyar, B. (2020). Does globalization and financial sector development affect environmental quality? A panel data investigation for the Middle East and North African countries. *Environmental Science and Pollution Research*, 1-14.

Bai, J., & Kao, C. (2006). On the estimation and inference of a panel cointegration model with cross-sectional dependence. *Contributions to economic analysis*, *274*, 3-30.

Bai, J., Kao, C., & Ng, S. (2009). Panel cointegration with global stochastic trends. *Journal of Econometrics*, *149*(1), 82-99.

Baloch, M. A., Zhang, J., Iqbal, K., & Iqbal, Z. (2019). The effect of financial development on ecological footprint in BRI countries: evidence from panel data estimation. *Environmental Science and Pollution Research*, *26*(6), 6199-6208.

Balsalobre-Lorente, D., Driha, O. M., Shahbaz, M., & Sinha, A. (2020). The effects of tourism and globalization over environmental degradation in developed countries. *Environmental Science and Pollution Research*, *27*(7), 7130-7144.

Bayar, Y., & Maxim, A. (2020). Financial Development and CO2 Emissions in Post-Transition European Union Countries. *Sustainability*, *12*(7), 2640.

Bekun, F. V., Alola, A. A., & Sarkodie, S. A. (2019). Toward a sustainable environment: Nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. *Science of the Total Environment*, *657*, 1023-1029.

Bilgili, F., Ulucak, R., Koçak, E., & İlkay, S. Ç. (2020). Does globalization matter for environmental sustainability? Empirical investigation for Turkey by Markov regime switching models. *Environmental Science and Pollution Research*, *27*(1), 1087-1100.

Boutabba, M. A. (2014). The impact of financial development, income, energy and trade on carbon emissions: evidence from the Indian economy. Economic Modelling, 40, 33-41.

Boutabba, M. A., Diaw, D., & Lessoua, A. (2018). Environment-energy-growth nexus in Sub Saharan Africa: The role of intermediate goods. *International economics*, *156*, 254-267.

Chen, S., Saud, S., Saleem, N., & Bari, M. W. (2019). Nexus between financial development, energy consumption, income level, and ecological footprint in CEE countries: do human capital and biocapacity matter?. *Environmental Science and Pollution Research*, *26*(31), 31856-31872.

Claessens, S., & Feijen, E. (2007). *Financial sector development and the millennium development goals*. The World Bank.

Destek, M. A. (2019a). Financial Development and Environmental Degradation in Emerging Economies. In *Energy and Environmental Strategies in the Era of Globalization* (pp. 115-132). Springer, Cham.

Destek, M. A. (2019b). Investigation on the role of economic, social, and political globalization on environment: evidence from CEECs. *Environmental Science and Pollution Research*, 1-14.

Destek, M. A., & Aslan, A. (2020). Disaggregated renewable energy consumptio and environmental pollution nexus in G-7 countries. *Renewable Energy*, *151*, 1298-1306.

Destek, M. A., & Sarkodie, S. A. (2019). Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development. *Science of the Total Environment*, *650*, 2483-2489.

Destek, M. A., & Sinha, A. (2020). Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic Co-operation and development countries. *Journal of Cleaner Production*, *242*, 118537.

Destek, M. A., Ulucak, R., & Dogan, E. (2018). Analyzing the environmental Kuznets curve for the EU countries: the role of ecological footprint. *Environmental Science and Pollution Research*, *25*(29), 29387-29396.

Dietz, T., & Rosa, E. A. (1994). Rethinking the environmental impacts of population, affluence and technology. *Human ecology review*, *1*(2), 277-300.

Dietz, T., & Rosa, E. A. (1997). Environmental impacts of population and consumption. *Environmentally significant consumption: Research directions*, 92-99.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: a survey. *Ecological economics*, *49*(4), 431-455.

Dogan, E., & Seker, F. (2016). The influence of real output, renewable and non-renewable energy, trade and financial development on carbon emissions in the top renewable energy countries. *Renewable and Sustainable Energy Reviews*, *60*, 1074-1085.

Dong, F., Wang, Y., Su, B., Hua, Y., & Zhang, Y. (2019). The process of peak CO2 emissions in developed economies: A perspective of industrialization and urbanization. *Resources, Conservation and Recycling*, *141*, 61-75.

Ehrlich, P. R., & Holdren, J. P. (1971). Impact of population growth. *Science*, *171*(3977), 1212-1217.

Erdogan, S., Okumus, I., & Guzel, A. E. (2020). Revisiting the Environmental Kuznets Curve hypothesis in OECD countries: the role of renewable, non-renewable energy, and oil prices. *Environmental Science and Pollution Research*, 1-9.

Fan, H., & Hossain, M. I. (2018). Technological Innovation, Trade Openness, CO2 Emission and Economic Growth: Comparative Analysis between China and India. *International Journal of Energy Economics and Policy*, *8*(6), 240.

Fei, Q., Rasiah, R., & Shen, L. J. (2014). The clean energy-growth nexus with CO2 emissions and technological innovation in Norway and New Zealand. *Energy & environment*, *25*(8), 1323-1344.

Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement. National Bureau of Economic Research (No. w3914).

Hang, G., & Yuan-Sheng, J. (2011). The relationship between CO2 emissions, economic scale, technology, income and population in China. *Procedia Environmental Sciences*, *11*, 1183-1188.

Hashmi, R., & Alam, K. (2019). Dynamic relationship among environmental regulation, innovation, CO2 emissions, population, and economic growth in OECD countries: A panel investigation. *Journal of cleaner production*, *231*, 1100-1109.

Ibrahiem, D. M. (2020). Do technological innovations and financial development improve environmental quality in Egypt?. *Environmental Science and Pollution Research*, 1-13.

Irandoust, M. (2016). The renewable energy-growth nexus with carbon emissions and technological innovation: Evidence from the Nordic countries. *Ecological Indicators*, *69*, 118 125.

Islam, F., Shahbaz, M., Ahmed, A. U., & Alam, M. M. (2013). Financial development and energy consumption nexus in Malaysia: a multivariate time series analysis. *Economic Modelling*, *30*, 435-441.

Jalil, A., & Feridun, M. (2011). The impact of growth, energy and financial development on the environment in China: a cointegration analysis. *Energy Economics*, *33*(2), 284-291.

Jensen, A. L. (1996). Beverton and Holt life history invariants result from optimal trade-off of reproduction and survival. *Canadian Journal of Fisheries and Aquatic Sciences*, *53*(4), 820-822.

Khan, D., & Ulucak, R. (2020). How do environmental technologies affect green growth? Evidence from BRICS economies. *Science of The Total Environment*, 136504.

Khan, M. T. I., Yaseen, M. R., & Ali, Q. (2019). Nexus between financial development, tourism, renewable energy, and greenhouse gas emission in high-income countries: A continent-wise analysis. *Energy Economics*, *83*, 293-310.

Khattak, S. I., Ahmad, M., Khan, Z. U., & Khan, A. (2020). Exploring the impact of innovation, renewable energy consumption, and income on CO2 emissions: new evidence from the BRICS economies. *Environmental Science and Pollution Research*, 1-16.

Kuznets, S. (1955). Economic growth and income inequality. *The American economic review*, *45*(1), 1-28.

Lin, B., Omoju, O. E., Nwakeze, N. M., Okonkwo, J. U., & Megbowon, E. T. (2016). Is the environmental Kuznets curve hypothesis a sound basis for environmental policy in Africa?. *Journal of Cleaner Production*, *133*, 712-724.

Liu, H., & Song, Y. (2020). Financial development and carbon emissions in China since the recent world financial crisis: Evidence from a spatial-temporal analysis and a spatial Durbin model. *Science of The Total Environment*, *715*, 136771.

Liu, X., & Bae, J. (2018). Urbanization and industrialization impact of CO2 emissions in China. *Journal of cleaner production*, *172*, 178-186.

Moghadam, H. E., & Lotfalipour, M. R. (2014). Impact of financial development on the environmental quality in Iran. *Chinese Business Review*, *13*(9), 537-551.

Muntean, M., Guizzardi, D., Schaaf, E., Crippa, M., Solazzo, E., Olivier, J., & Vignati, E. (2018). Fossil CO2 emissions of all world countries. *Luxembourg: Publications Office of the European Union*.

Nasir, M. A., Huynh, T. L. D., & Tram, H. T. X. (2019). Role of financial development, economic growth & foreign direct investment in driving climate change: A case of emerging ASEAN. *Journal of environmental management*, *242*, 131-141.

Ozturk, I., & Acaravci, A. (2013). The long-run and causal analysis of energy, growth, openness and financial development on carbon emissions in Turkey. *Energy Economics*, *36*, 262-267.

Rafindadi, A. A., & Usman, O. (2019). Globalization, energy use, and environmental degradation in South Africa: Startling empirical evidence from the Maki-cointegration test. *Journal of environmental management*, *244*, 265-275.

Salahuddin, M., Ali, M. I., Vink, N., & Gow, J. (2019). The effects of urbanization and globalization on CO 2 emissions: evidence from the Sub-Saharan Africa (SSA) countries. *Environmental Science and Pollution Research*, *26*(3), 2699-2709.

Samargandi, N. (2017). Sector value addition, technology and CO2 emissions in Saudi Arabia. *Renewable and Sustainable Energy Reviews*, *78*, 868-877.

Sarkodie, S. A., Adams, S., Owusu, P. A., Leirvik, T., & Ozturk, I. (2020). Mitigating degradation and emissions in China: The role of environmental sustainability, human capital and renewable energy. *Science of the Total Environment*, 137530.

Shafik, N., Bandyopadhyay, S., 1992. Economic growth and environmental quality: time-series and cross-country evidence. World Development Report Working Paper WPS 904, The World Bank, Washington, DC.

Shahbaz M, Sinha A (2019) Environmental Kuznets curve for $CO_2$ emissions: a literature survey. Journal of Economic Studies 46(1):106-168.

Shahbaz, M., Destek, M. A., & Polemis, M. L. (2018a). Do Foreign Capital and Financial Development Affect Clean Energy Consumption and Carbon Emissions? Evidence from BRICS and Next-11 Countries. *SPOUDAI-Journal of Economics and Business*, *68*(4), 20-50.

Shahbaz, M., Haouas, I., Sohag, K., & Ozturk, I. (2020). The financial development-environmental degradation nexus in the United Arab Emirates: the importance of growth, globalization and structural breaks. *Environmental Science and Pollution Research*, 1-15.

Shahbaz, M., Mallick, H., Mahalik, M. K., & Loganathan, N. (2015). Does globalization impede environmental quality in India?. *Ecological Indicators*, *52*, 379-393.

Shahbaz, M., Nasir, M. A., & Roubaud, D. (2018b). Environmental degradation in France: the effects of FDI, financial development, and energy innovations. *Energy Economics*, *74*, 843-857.

Shahbaz, M., Shahzad, S. J. H., Ahmad, N., & Alam, S. (2016). Financial development and environmental quality: The way forward. *Energy Policy*, *98*, 353-364.

Shahbaz, M., Solarin, S. A., Mahmood, H., & Arouri, M. (2013a). Does financial development reduce CO2 emissions in Malaysian economy? A time series analysis. *Economic Modelling*, *35*, 145-152.

Shahbaz, M., Tiwari, A. K., & Nasir, M. (2013b). The effects of financial development, economic growth, coal consumption and trade openness on CO2 emissions in South Africa. *Energy Policy*, *61*, 1452-1459.

Sharif, A., Baris-Tuzemen, O., Uzuner, G., Ozturk, I., & Sinha, A. (2020). Revisiting the role of renewable and non-renewable energy consumption on Turkey's ecological footprint: Evidence from Quantile ARDL approach. *Sustainable Cities and Society*, 102138.

Sinha, A., Sengupta, T., & Alvarado, R. (2020). Interplay between technological innovation and environmental quality: formulating the SDG policies for next 11 economies. *Journal of Cleaner Production*, *242*, 118549.

Tamazian, A., Chousa, J. P., & Vadlamannati, K. C. (2009). Does higher economic and financial development lead to environmental degradation: evidence from BRIC countries. *Energy policy*, *37*(1), 246-253.

Torras, M., & Boyce, J. K. (1998). Income, inequality, and pollution: a reassessment of the environmental Kuznets curve. *Ecological economics*, *25*(2), 147-160.

Ulucak, R., & Khan, S. U. D. (2020). Determinants of the ecological footprint: Role of renewable energy, natural resources, and urbanization. *Sustainable Cities and Society*, *54*, 101996.

Vukina T, Beghin JC, Solakoglu E.G (1999) Transition to markets and the environment: effects of the change in the composition of manufacturing output. Environ Dev Econ 4: 582 598.

Wackernagel, M., & Rees, W. (1996). *Our ecological footprint: reducing human impact on the earth* (Vol. 9). New society publishers.

Wang, Q., & Su, M. (2019). The effects of urbanization and industrialization on decoupling economic growth from carbon emission–A case study of China. *Sustainable Cities and Society*, *51*, 101758.

Wang, Z., Rasool, Y., Asghar, M. M., & Wang, B. (2019). Dynamic linkages among CO 2 emissions, human development, financial development, and globalization: empirical evidence based on PMG long-run panel estimation. *Environmental Science and Pollution Research*, *26*(36), 36248-36263.

Wang, Z., Rasool, Y., Zhang, B., Ahmed, Z., & Wang, B. (2020). Dynamic linkage among industrialisation, urbanisation, and CO2 emissions in APEC realms: Evidence based on DSUR estimation. *Structural Change and Economic Dynamics*, *52*, 382-389.

Yii, K. J., & Geetha, C. (2017). The nexus between technology innovation and CO2 emissions in Malaysia: evidence from granger causality test. *Energy Procedia*, *105*, 3118-3124.

Yin J, Zheng M, Chen J (2015) The effects of environmental regulation and technical progress on $CO_2$ Kuznets curve: An evidence from China. Energy Policy 77:97-108.

Yu, Y., & Du, Y. (2019). Impact of technological innovation on CO2 emissions and emissions trend prediction on 'New Normal'economy in China. *Atmospheric Pollution Research*, *10*(1), 152-161.

Zafar, M. W., Shahbaz, M., Sinha, A., Sengupta, T., & Qin, Q. (2020). How renewable energy consumption contribute to environmental quality? The role of education in OECD countries. *Journal of Cleaner Production*, 122149.

Zafar, M. W., Zaidi, S. A. H., Sinha, A., Gedikli, A., & Hou, F. (2019). The role of stock market and banking sector development, and renewable energy consumption in carbon emissions: Insights from G-7 and N-11 countries. *Resources Policy*, *62*, 427-436.

Zhang, Y. J. (2011). The impact of financial development on carbon emissions: An empirical analysis in China. *Energy policy*, *39*(4), 2197-2203.